RESEARCH OF MATERIALS SUITABILITY FOR CRACK REPAIR IN REINFORCED CONCRETE STRUCTURES

Rytis Skominas*, Vincas Gurskis, Algimantas Patasius*****
Aleksandras Stulginskis University, Institute of Hydraulic Constructional Engineering
E-mail: *rytis.skominas@asu.lt, **vincas.gurskis@asu.lt, ***algimantas.patasius@asu.lt

ABSTRACT

Cracks are one of the serious problems appearing in reinforced concrete. The reasons that cause the cracking of structures could be different: load impact, corrosion of reinforcement, unsteady settlement of framework, environmental effect etc. The cracks cause a decrease of the structure's durability and longevity. Therefore it is important to repair damaged structures.

To estimate the materials' suitability for crack repair a slant shear strength test and a water penetration test were used. The results show that polymer injection materials A and B can restore the strength of concrete. The repair carried out with modified cementitious material (for modification used expansive additive and polymer additive) has the same effect. Water penetration test shows, that all polymer injection materials are quite water resistant.

Keywords: reinforced concrete, crack, repair, cementitious material, injection material.

INTRODUCTION

Reinforced concrete structures are one of the most popular in the world. They are often used in civil and hydraulic engineering. During their service time, reinforced concrete structures tend to deteriorate. Cracks are one of the biggest problems appearing in reinforced concrete. The reasons that cause cracking of structures could be different: load impact, corrosion of reinforcement, unsteady settlement of framework,environmental effects, etc. The cracks cause the decrease of the structure's durability and longevity (Poursaee et al., 2008; Vidal et al., 2004; Zhao et al., 2011). Therefore, it is important to repair these damaged structures. Different repair techniques have been successfully developed to strengthen a given structure or part of it to restore its serviceability and strength. It is also prudent to consider the durability aspect when repair or strengthening is carried out. The final selection of a suitable and most effective method generally depends on simplicity, speed of application, structural performance and total cost (Thanoon et al., 2005). The proper repair of cracks depends on knowing the causes and selecting the repair procedures that take these causes into account; otherwise, the repair may only be temporary. Successful long-term repair procedures must attack the causes of the cracks as well as the cracks themselves (Issa et al., 2007).

Nowadays all manufacturers of repair materials try to improve their products in order to give more universal and technologically simpler repair materials for the market.

There are a number of studies carried out on crack repair. In scientific articles it is possible to find about crack repair using cementitious materials with shrinkable polymers (Ahmad et al., 2012; Jefferson et al., 2010), epoxy repair systems (Issa et al., 2007; Shin et al., 2011), synthesizing super-absorbent resins (Song et al., 2009). Kim Van Tittelboom, Nele De Belie, Willem De Muynck, Willy Verstraete and Jianyun Wang (2010; 2012) recomends to use a bacteria to repair cracks in concrete. Ureolytic bacteria such as Bacillus sphaericus are able to precipitate $CaCO_3$ in their micro-environment by conversion of urea into ammonium and carbonate. The bacterial degradation of urea locally increases the pH and promotes the microbial deposition of carbonate as calcium carbonate in a calcium rich environment. These precipitated crystals can thus fill the cracks.

It is of considerable interest to compare commercially available injection materials with cementitious materials and to estimate the suitability of them for the cracks repair in different conditions.

MATERIALS

In the research 3 cementitious mortars (1st without additives, 2nd modified with expansive additive and 3rd modified with polymer additive) and 4 different polymer injection materials were used.

Cementitious mortars were prepared using the Portland cement CEM II/A–L–42,5N, natural sand (fraction 0…1 mm) and water. Sand and water meet the requirements described in European standards EN 13139:2002 and EN 1008:2002. For modification of cementitious mortars the expansive additive (5 % amount from mass of cement) and acryl based polymer additive (10 % amount from mass of cement) were used.

Injection material *A* is a low viscosity polyurethane-based elastomer resin for use in flexible sealing and filling of cracks, joints and voids in building construction, underground and civil engineering under dry, water-bearing and high-pressure water-bearing conditions.

Injection material *B* is a low viscosity duromer resin based on epoxy for use in rigid filling of cracks, joints and voids in building construction, civil and underground engineering under dry and slightly damp conditions.
Injection material *C* is a polyurethane-based adhesive for use in tamping of cracks and open voids for force fit and non-force fit injection in construction and civil engineering under dry conditions.
Injection material *D* is a low viscosity polymer-modified, acrylic-based hydro-structural resin for use in sealing injection of joints, cracks and cavities in masonry and concrete without reinforcement.
As a base, for the slant shear strength test fine-grained concrete specimens (160×40×40 mm) were prepared using the Portland cement CEM II/A–L–42.5 N, natural sand (fraction 0…4 mm) and water. Sand and water meet the requirements described in European standards EN 13139:2002 and EN 1008:2002.
In order to evaluate the watertightness of the repaired cracks, concrete specimens (d=150 mm, D=180 mm, h=150 mm) were prepared using Portland cement CEM II/A–L–42.5 N, natural gravel (fraction 4…16 mm), natural sand (fraction 0…4 mm) and water. Gravel, sand and water meet the requirements described in European standards EN 12620:2002+A1:2008 and EN 1008:2002.The strength class of concrete specimens C30/37.

TEST METHODS

In order to evaluate the compression and flexural strength of mortars, the specimens (40×40×160 mm) were prepared and tested after 28 days by standard test methods (EN 196-1:2007).
The slant shear strength of the repaired specimens was estimated according to the European standard EN 12615:1999. The principal scheme of specimen used in test is presented in figure 1. Performing a test the specimens were splited into the two parts according to the requirements presented in standard. Subsequently the specimen's parts were pasted with repair materials and tested for compression.

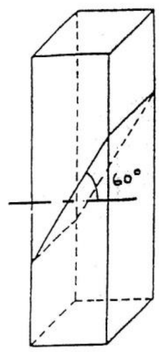

Figure 1. Principal scheme of specimen

The watertightness of repaired cracks was estimated according to the European standard EN 12390-8:2009. Before the test specimens were splited into the two parts and pasted with repair materials. The test lasted 72 hours pressing the specimens with 5 atm. water pressure and keeping the close watch on leakage.

TEST RESULTS AND DISCUSSION

In order to estimate the influence of expansive and polymer additives on mortar, the specimens (40×40×160 mm) with and without additives were made, and they were tested after 28 days of solidification (1 day in the form and 27 days in the water). The test results of flexure and compression strength are presented in Table 1.
The test results show that modification of mortar has a positive effect on the mechanical properties of mortar. The compression strength of mortar increased by 12 % using an expansive additive and by 39 % using a polymer additive. The flexure strength of mortar increased by 21 % using an expansive additive and by 6 % using a polymer additive

Table 1

Test results of fresh mortar which are used for crack repair

Cementitious mortar	Flexure strength, N/mm^2	Compression strength, N/mm^2
Non modified cementitious mortar	4.40	20.94
Cementitious mortar modified with expansive additive	5.33	23.50
Cementitious mortar modified with polymer additive	4.68	29.10

.

During the slant shear test, two different failure types of specimens occurred (Table 2). The failure type of specimens repaired with polymer injection materials *A*, *B* and *D* was cohesive through mortar substrate (A). The failure type of specimens repaired with all cementitious mortars and polymer injection material *C* was dual (A/B) – partly cohesive through mortar substrate and partly adhesive between mortar substrate and repair material. According to the dual failure results (Table 2) the dominant average (76.7 – 91.2 %) of

failure is cohesive. Summarizing the results it is possible to state that all repair materials carry sufficient adhesive features, because of worst case only 23.3 % of specimen failure was adhesive (between mortar substrate and repair material).
Evaluating the strength of the repaired concrete a slant shear test was used and determined that all the repair materials had various influences (Figure 2). Comparing the strength of repaired specimens the results can be grouped into three types: a) the strength decreased by more than 5 %; b) the strength decreased under 5 %; c) the strength increased.

Table 2

The specimens failure types

Repaired crack with	Failure, %		
	Type A (cohesive through mortar substrate)	Type B (adhesive between mortar substrate and repair material)	Type A/B (partly cohesive through mortar substrate and partly adhesive between mortar substrate and repair material)
Cementitious mortar	-	-	(82.5/17.5)
Cementitious mortar modified with expansive additive	-	-	(76.7/23.3)
Cementitious mortar modified with polymer additive	-	-	(78.0/22.0)
Polymer injection material *A*	100	-	-
Polymer injection material *B*	100	-	-
Polymer injection material *C*	-	-	(91.2/8.8)
Polymer injection material *D*	100	-	-

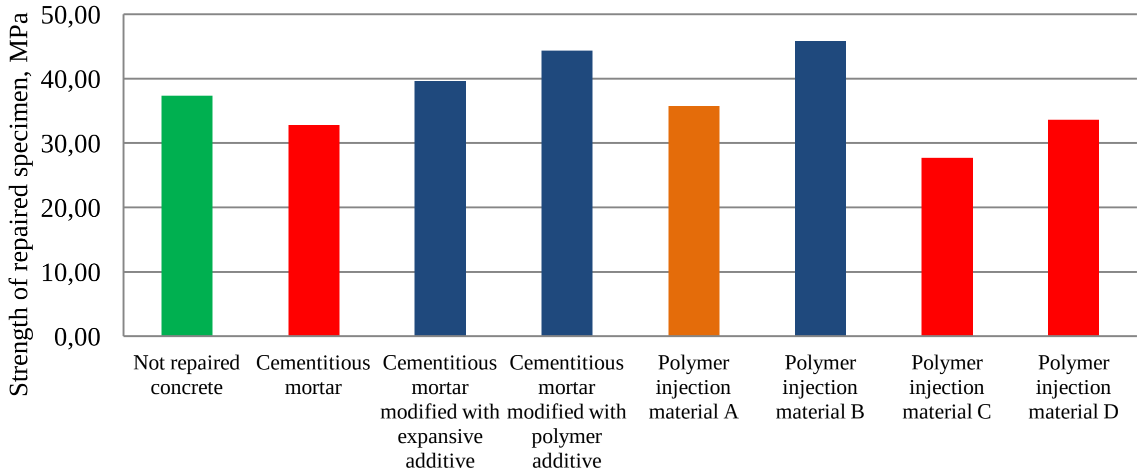

Figure 2. Repair materials influence on specimen strength

In the first group (red color in Figure 2) there are non-modified cementitious mortar (strength decreased by 12.2 %) and injection materials *C* and *D* (strength decreased by 25.8 % and 9.9 % respectively). All these materials are not suitable for constructional repair and can be used only for non-constructional repair. It is noticeable, that according to the manufacturer's technical data of injection materials *C* and *D* that they are not useful for constructional repair. These two materials are suitable for moving crack repair, where elastic materials are needed. So the research confirms the

information published in the technical list of materials.
In the second group (orange color in Figure 2), there are injection material *A* (strength decreased by 4.3 %). As we see the strength loss did not reach 5 %, therefore it can be used for constructional repair.
In the third group (blue color in Figure 2) are cementitious mortars modified with expansive and polymer additives (strength increased by 6.1 % and 15.8 % respectively) and injection material *B* (strength increased by 18.3 %). The modification of cementitious mortar with an expansive additive decreased the shrinkage deformations, therefore the mortars have better adhesive properties. The polymer additive increased the sticky properties of the mortar, which partly penetrated into the concrete surface and formed a solid monolith. In all three cases the strength of specimens increased due the achieved monolithic performance between repair materials and parent concrete.
The results of water tightness test show (Table 3), that all tested injection materials are suitable for the crack's repair when the purpose of repair is hermetisation. The injection materials not let in water through the repaired specimen over the test time (72 hours). Therefore, these materials are suitable for repair in environmental exposure classes XO, XC, XD, XS and XF.

Table 3

Water tightness of repaired cracks

Repaired concrete with	Water penetration through the specimen time
Cementitious mortar	17 min
Cementitious mortar modified with expansive additive	33 min
Cementitious mortar modified with polymer additive	19 min
Polymer injection material *A*	> 72 h
Polymer injection material *B*	> 72 h
Polymer injection material *C*	> 72 h
Polymer injection material *D*	> 72 h

The cementitious materials show different results comparing them with injection materials. The water penetrated through the repaired cracks with all cementitious materials in a short time (17 – 33 min). Such fluctuation is connected with shrinkage deformations, which occur during the solidification of mortars. The shrinkage of the solidified concrete is lower during its drying as compared to mortar during its solidification. Using the expansive additive, the comparative shrinkage deformation decreased as compared to the mortar prepared without expansive additive, but not enough. With the weaker shrinkage, acting intermolecular forces become weaker as well, due to which mortar particles lose the bond. This influenced the microcracking in the mortar. In such case, the cementing materials used in research are suitable for repair in the environmental exposure class XO.

CONCLUSIONS

1. According to the failure types of the slant shear test the dominant failure is cohesive. Therefore, it is possible to state, that all repair materials used in the research carry sufficient adhesive features.
2. The cementitious mortar modified with expansive and polymer additives and injection materials *A* and *B* are suitable for constructional repair. Other repair materials (non-modified cementitious mortar and injection materials *C* and *D*) used in the research proved to be suitable only for non-constructional repair.
3. Having carried out research of water tightness it was determined that all injection materials used in the research are suitable for repair in environmental exposure classes XO, XC, XD, XS and XF. The cementitious mortars used in the research are suitable only for repair in environmental exposure classes XO.

REFERENCES

Ahmad S., Elahi A., Barbhuiya S. A., Farid Y. (2012) Use of polymer modified mortar in controlling cracks in reinforced concrete beams. *Construction and Building Materials* Vol. 27, p. 91-96.

EN 196-1:2005 Methods of testing cement - Part 1: Determination of strength.

EN 1008:2002 Mixing water for concrete - Specification for sampling, testing and assessing the suitability of water, including water recovered from processes in the concrete industry, as mixing water for concrete.

EN 12390-8:2009 Testing hardened concrete - Part 8: Depth of penetration of water under pressure.

EN 12615:1999 Products and systems for the protection and repair of concrete structures - Test methods - Determination of slant shear strength.

EN 12620:2002 Aggregates for concrete.

EN 13139:2002 Aggregates for mortar.

Issa C. A., Debs P. (2007) Experimental study of epoxy repairing of cracks in concrete. *Construction and Building Materials* Vol. 21, p. 157-163.

Jefferson A., Joseph C., Lark R., Isaacs B., Dunn S, Weager B. (2010) A new system for crack closure of cementitious materials using shrinkable polymers. *Cement and Concrete Research* Vol. 40, p. 795-801.

Poursaee. A., Hansson. C.M. (2008) The influence of longitudinal cracks on the corrosion protection afforded reinforcing steel in high performance concrete. *Cement and Concrete Research* Vol. 38, p. 1098-1105.

Shin. H.C., Miyauchi. H., Tanaka. K. (2011) An experimental study of fatigue resistance in epoxy injection for cracked mortar and concrete considering the temperature effect. *Construction and Building Materials* Vol. 25, p. 1316-1324.

Song. X.F., Wei. J.F., He.T.SH. (2009) A method to repair concrete leakage through cracks by synthesizing super-absorbent resin in situ. *Construction and Building Materials* Vol. 23, p. 386-391.

Thanoon. W.A., Jaafar. M.S., Razali. A., Kardin. A., Noorzaei. J. (2005) Repair and structural performance of initially cracked reinforced concrete slabs. *Construction and Building Materials* Vol. 19, p. 595-603.

Tittelboom. K.V., De Belie. N., Muynck. W.D., Verstraete. W. (2010) Use of bacteria to repair cracks in concrete. *Cement and Concrete Research* Vol. 40, p. 157-166.

Wang J., Tittelboom K. V., De Belie N., Verstraete W. (2012) Use of silica gel or polyurethane immobilized bacteria for self-healing concrete. *Construction and Building Materials* Vol. 26, p. 532-540.

Vidal. T., Castel. A., Francois. R. (2004) Analyzing crack width to predict corrosion in reinforced concrete. *Cement and Concrete Research* Vol. 34, p. 165-174.

Zhao Y., Yu J., Jin W. (2011) Damage analysis and cracking model of reinforced concrete structures with rebar corrosion. *Corrosion Science* Vol. 53, p. 3388-3397.